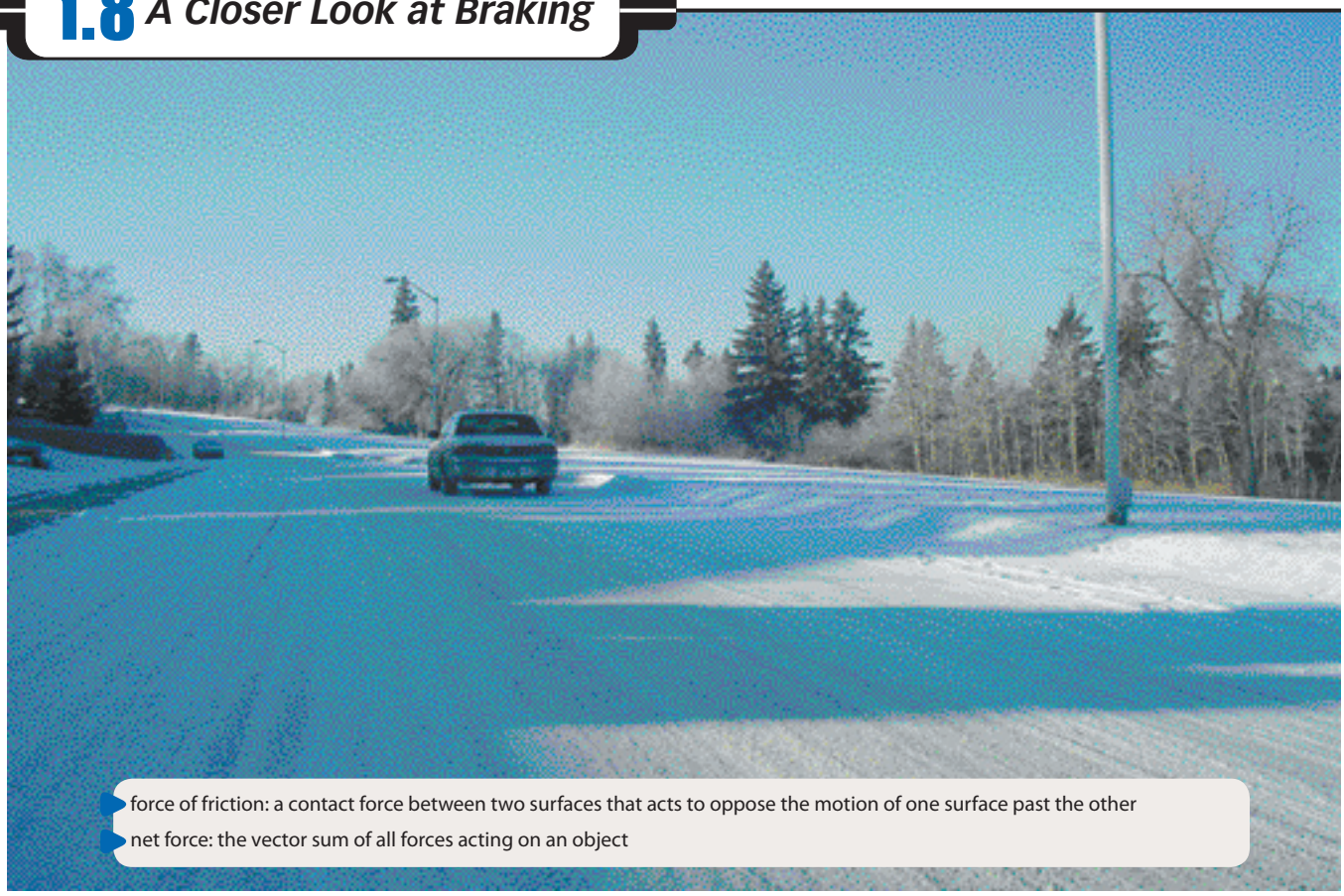
1.8 A Closer Look at Braking



force of friction: a contact force between two surfaces that acts to oppose the motion of one surface past the other

net force: the vector sum of all forces acting on an object

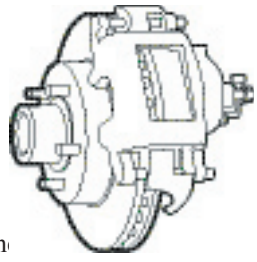
Figure B1.46: The ability to slow down a vehicle relies on a number of factors.

Earlier in this chapter you found that the stopping distance for a vehicle is the sum of the reaction distance and the braking distance. Both of these quantities depend upon the initial velocity of the vehicle. In addition, the reaction distance depends upon the reaction time of the driver, and the braking distance depends upon the ability of the vehicle to decelerate. Recall that 5.85 m/s^2 was used as a deceleration value representative of the performance of most vehicles. In fact, the ability of a vehicle to decelerate can vary greatly depending upon the particular circumstances.

Factors Determining a Vehicle's Deceleration Value

Your experiences in vehicles on icy winter roads should confirm that the traction between the tires and the roadway plays a significant role in the ability of a vehicle to decelerate. Many people have had the scary experience of being in a vehicle that slid straight through an intersection. In these instances, the inability of the vehicle to decelerate was due largely to the fact that the **force of friction** between the vehicle's tires and the road was too low. The pattern of raised tread on a tire is designed to reduce slippage and allow the tire to effectively grip the road. This kind of friction is desirable and is absolutely necessary for both braking and moving the vehicle.

Like all forces, friction is a push or a pull that is measured in newtons. When you hold a small apple in your hand, gravity pulls down on the apple with a force of about 1 N. Since a force is a quantity with direction, it is classified as a vector. It can take thousands of newtons of force acting in the direction opposite to that of the velocity vector to bring a vehicle to a stop. For a vehicle travelling at low speed on a level roadway, taking your foot off the accelerator and allowing the car to coast produces only hundreds of newtons of frictional forces from air and road resistance. This is much less than the thousands of newtons needed to stop the vehicle promptly.



Brakes—particularly brake pads and rotors—are designed to produce additional friction between th rotating wheels and the fixed frame of the vehicle. When a vehicle is braking, there are three frictional forces present: force of air resistance, force of road resistance, and the force applied by the braking system. The sum of these forces is called **net force**. In this context, the word *net* means "sum" or "total," as all three forces are acting in the same direction and serve to slow the vehicle down.

Practice

43. When winter driving conditions get very icy, sand is often put on the roadway. Explain why this helps drivers brake and turn with greater safety.

The Effect of Mass

Another factor that affects the rate of deceleration is the **mass** of the vehicle, which is a scalar quantity usually measured in kilograms. Because a transport truck has a mass that is many thousands of kilograms greater than a typical passenger car, a truck driver approaching a red light at an intersection must start the process of deceleration much sooner.

mass: the quantity of matter in an object

Figure B1.47: Entering a truck's "no zone" can be very dangerous.

Practice

44. A driver of a large transport truck on a highway sometimes refers to the space immediately in front of the moving truck as the "no zone." It's called this because no other vehicle should ever slip into this space. Explain why the "no zone" is for the safety of other passenger vehicles as well as for the truck driver.

DID YOU KNOW?

What do skateboarding and snowboarding have in common with sumo wrestling? What do any of them have to do with mass and highway transportation?

In these sports, maintaining your balance so you don't fall over is essential. This is accomplished by positioning the body in a crouched position with the knees bent. This position lowers the centre of mass in the body. Since falling over happens when the centre of mass moves past the outside edge of your foot, having a wide stance increases stability.

Centre of mass is also an important consideration for trucking and highway transportation. The chance of rollover can be reduced if the centre of mass of the truck and cargo is as low as possible. Although a truck can't bend its knees and crouch down, it can be loaded in a way that keeps the more massive items as low as possible. This also explains why transport trucks tend to be so wide—it's their version of a wide stance.

What is the relationship among net force, mass, and the rate of deceleration? In the next activity you will have an opportunity to use the computer applet "Newton's Second Law." You will test different combinations of variables to determine their effect on the deceleration of the vehicle. The applet will provide you with a collection of animated vehicles and relevant data.

Utilizing Technology

Factors Influencing the Rate of Deceleration

Purpose

You will use the applet "Newton's Second Law," found on the Science 20 Textbook CD, to explore relationships among net force, mass, and rate of deceleration. Since this activity deals with braking, the term force of friction refers mainly to the forces between the internal parts of a vehicle's brake system.

Background

Before starting, familiarize yourself with the features of the applet by entering random values, clicking the Go button, and seeing what happens. Remember to click the Reset button before you enter new values to begin a new trial.

Part A: Varying the Mass of the Vehicle

Science Skills

✓ Analyzing and Interpreting

Procedure

step 1: Copy the following data sheet into your notebook or into a spreadsheet.

Part A: Varying the Mass of the Vehicle

Constant Values

Force of Friction = _____

Initial Velocity = _____

Applied Force = _____

Mass (kg)	Acceleration (m/s^2)	Net Force (N)
1000		
2000		
3000		
4000		
5000		

step 2: Select the constant values in the applet: Force of Friction = -6000 N, Initial Velocity = +4.00 m/s, and Applied Force = 0. These values will be kept constant throughout this part of the activity. Record these values in the appropriate places on the data sheet.

step 3: Set the initial value of the mass of the vehicle to 1000 kg.

step 4: Click the Go button, and observe the motion of the vehicle. Record the values of the acceleration and the net force for this trial in the appropriate place on the data sheet.

step 5: Repeat steps 3 and 4 for each of the following vehicle masses: 2000 kg, 3000 kg, 4000 kg, and 5000 kg. Record the values of the corresponding acceleration and the net force for each mass.

Analysis

1. Describe the trend in the data by completing the following statement:

   As the mass of the vehicle increases, and the force of friction is kept constant, the magnitude of the acceleration _____.

2. The word net means "sum" or "total." Explain why the net force is the same value as the force of friction in each of these trials.
3. Compare the directions of the acceleration and the net force as revealed by the sign convention.

Part B: Varying the Net Force

Procedure

step 1: Copy the following data sheet into your notebook or into a spreadsheet.

Part B: Varying the Net Force

Constant Values

Mass = _____

Initial Velocity = _____

Applied Force = _____

Force of Friction (N)	Net Force (N)	Acceleration (m/s^2)
-5000		
-4000		
-3000		
-2000		
-1000		
0		

step 2: Select the constant values in the applet: Mass = 1000 kg, Initial Velocity = +4.00 m/s, and Applied Force = 0. These values will be kept constant throughout this part of the investigation. Record these values in the appropriate places on the data sheet.

step 3: Set the initial value of the force of friction to -5000 N. Note that the negative sign indicates that the force of friction is acting in the direction opposite to that of the vehicle.

step 4: Click the Go button, and observe the motion of the vehicle. Record the value of the net force and the acceleration for this trial in the appropriate place on the data sheet.

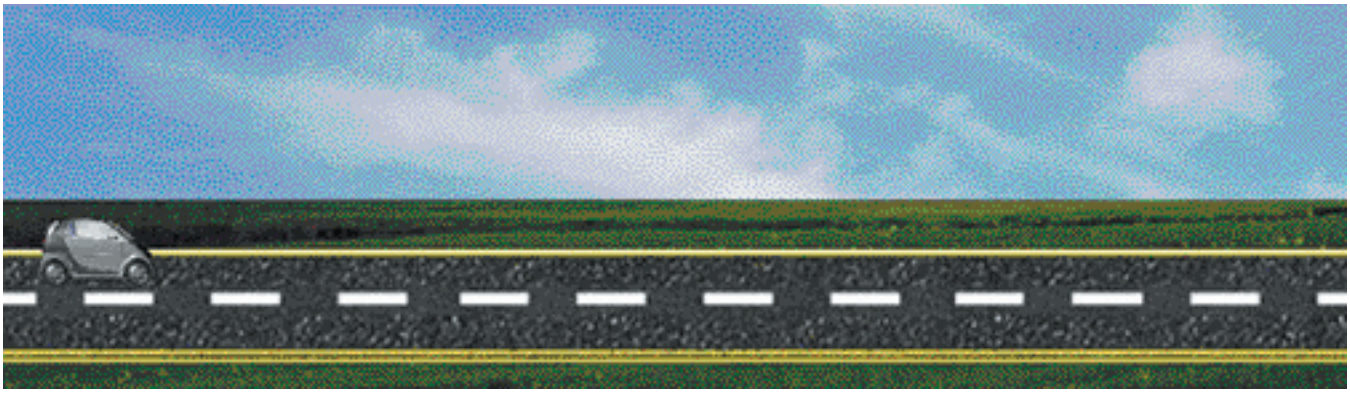
step 5: Repeat steps 3 and 4 for each of the following values of the force of friction: -4000 N, -3000 N, -2000 N, -1000 N, and 0. Record the values of the corresponding net force and acceleration for each value of the force of friction.

Analysis

4. Describe the trend in the data by completing the following statement:

   As the magnitude of the net force decreases, the magnitude of the acceleration _____.

5. The last trial required you to enter a value of zero for the force of friction.
   a. Is it possible for the net force on a vehicle to be zero?
   b. Can you think of a circumstance in which the force of friction could be very small?
6. Compare the directions of the acceleration and the net force as revealed by the sign convention.



Newton's Second Law of Motion

The trends that you noticed in the previous investigation can be summarized in **Newton's second law of motion**. This law is best expressed in the following equation:

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

net force — acceleration — mass

Newton's second law of motion: a law stating that an object will accelerate in the direction of the net force

Usually, this law is written in terms of net force rather than in terms of acceleration. This is because the unit of force, the newton, is defined in terms of this equation:

Equation: $\vec{F}_{net} = m\vec{a}$

Units: $\mathrm{N} = (\mathrm{kg})(\mathrm{m/s^2})$

$\mathrm{N} = \mathrm{kg \cdot m/s^2}$

Example Problem 1.21

A vehicle with a mass of 1250 kg is travelling 45 km/h, east, when the driver engages the brakes to stop at an intersection.

a. If the net force on the vehicle is 7000 N west, determine the magnitude and direction of the deceleration of the vehicle while the net force is applied.

b. Determine the length of time the net force must be applied to stop the vehicle.

Solution

Let east be the positive direction and west be the negative direction.

a. $m = 1250\ \mathrm{kg}$

$\vec{F}_{net} = 7000\ \mathrm{N\,[W]}$

$= -7000\ \mathrm{N}$

$\vec{a} = ?$

$$\vec{F}_{net} = m\vec{a}$$

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

$$= \frac{-7000\ \mathrm{N}}{1250\ \mathrm{kg}}$$

$$= -5.600\ \mathrm{m/s^2}$$

The deceleration is 5.600 $\mathrm{m/s^2}$[W].

Figure B1.48: The ability to stop safely at an intersection is critical to the well-being of you and those around you.

b. Drop the vector notation since you are solving for time.

$a = -5.600\ \mathrm{m/s^2}$

$v_f = 0$

$v_i = 45\ \mathrm{km/h\,[E]}$

$$= +45\ \frac{\mathrm{km}}{\mathrm{h}} \times \frac{1000\ \mathrm{m}}{1\ \mathrm{km}} \times \frac{1\ \mathrm{h}}{3600\ \mathrm{s}}$$

$$= +12.5\ \mathrm{m/s}$$

$\Delta t = ?$

$$a = \frac{v_f - v_i}{\Delta t}$$

$$a = \frac{-v_i}{\Delta t} \quad \leftarrow v_f = 0$$

$$\Delta t = \frac{-v_i}{a}$$

$$= \frac{-(12.5\ \mathrm{m/s})}{(-5.600\ \mathrm{m/s^2})}$$

$= 2.2\ \mathrm{s}$ ¨ 2 significant digits, since velocity was initially given as 45 km/h

The net force must be applied for 2.2 s.

Practice

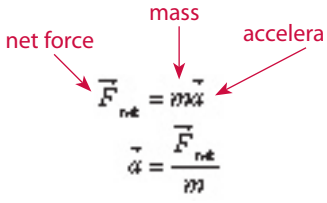
45. A farmer is on an errand to pick up supplies. The truck and em
trailer have a combined mass of 2920 kg. The winter driving c
require extra caution because the midday sun has melted just
enough of the packed snow to add a thin layer of water
between the tires and the road. Under these circumstances,
the maximum net force the farmer can expect for braking is
about 6500 N. Consider the initial velocity of the vehicle
to be in the positive direction.

    a. On the way to pick up supplies, the farmer—driving an empty truck and trailer—approaches an intersection with an initial velocity of 70.0 km/h. If the farmer has to stop at the intersection, calculate the deceleration of the truck and trailer.
    b. Determine the braking distance for the situation in question 45.a.
    c. On the way back, the farmer is carrying an additional 1250 kg of supplies on the flatbed trailer. The same intersection was approached with the same initial velocity. If the braking force remains the same, calculate the deceleration of the truck and trailer for these circumstances.
    d. Determine the braking distance for the situation in question 45.c.
    e. Given your answers to questions 45.b. and 45.d., what driving strategies could the farmer use when approaching the intersection with the massive load on the trailer?

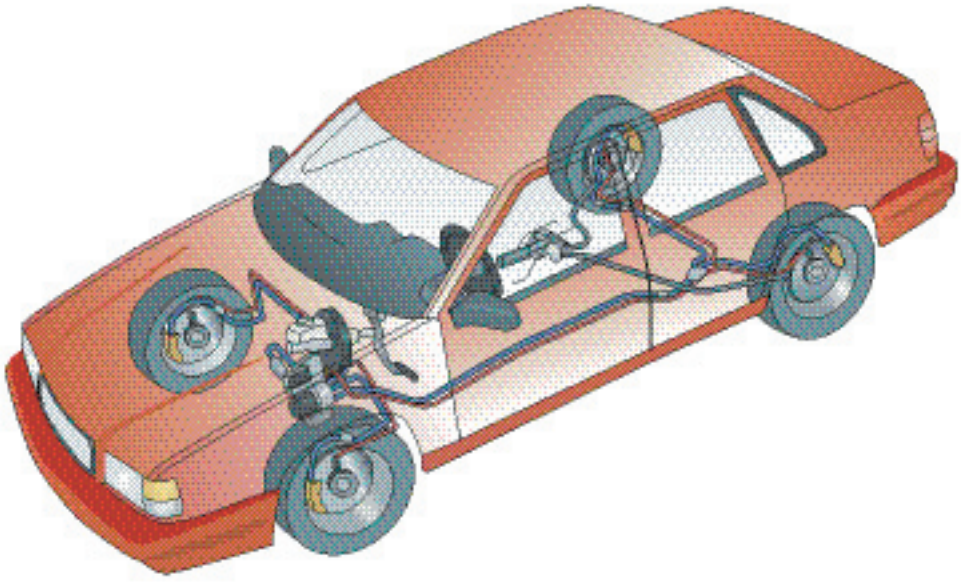
46. In Alberta, any trailer that has a mass of more than 2300 kg must be equipped with brakes controlled by the driver. Using your answers to question 45, provide a rationale for this law.

1.8 Summary

The force of friction is a contact force between two surfaces that acts to oppose the motion of one surface past another. During braking, the force of friction between internal parts of the vehicle's braking system, called brake pads and rotors, provides the net force to decelerate a moving vehicle. The relationships among net force, mass, and acceleration is described by Newton's second law of motion. This equation is usually written in terms of the net force; but it is best understood in terms of accelerat



In the case of braking, the direction of the net force and the acceleration both oppose the motion of the vehicle in the positive direction, so these values are negative.



1.8 Questions

Use the following information to answer questions 1 to 4.

A marvelous source of fun and exercise in the winter months is tobogganing and sledding. Toboggans have the advantage of carrying many people together down a hill for a frosty thrill ride. Sleds can only carry one or two people, but they are much more manoeuvrable. Some sleds even have steering wheels that control a front ski and brakes that can be applied by the driver. On a toboggan, steering is achieved by leaning to one side or the other and braking is accomplished by the riders digging their boots into the snow.

Figure B1.49: The three friends supply the force needed to accelerate the rider on the sled.

Figure B1.50: Boots digging into the snow can supply a braking force.

Knowledge

1. Imagine two sleds racing down a hill: one sled has two riders and the other has only one. Assume that the drivers of both sleds apply the brakes so that the same braking force is applied to each sled.

- **a.** Which sled will experience the greater deceleration?
- **b.** Use Newton's second law of motion to support your answer to question 1.a.

2. Imagine two toboggans moving down a hill, each loaded with four riders. On one toboggan, all four people dig their boots into the snow to provide the braking force at the end of the run. On the other toboggan, only the person in the front uses his or her boots to provide the braking force.

- **a.** Which toboggan will experience the greater deceleration?
- **b.** Use Newton's second law of motion to support your answer to question 2.a.

Applying Concepts

3. A toboggan travels the level terrain at the bottom of a hill with a velocity of 6.0 m/s, east. The riders dig in their boots and bring the toboggan to rest in 3.0 s. The mass of the toboggan and the riders is 185 kg.

- **a.** Sketch a diagram illustrating the braking process. Be sure to add arrows to represent the vector quantities of velocity, acceleration, and braking force.
- **b.** Calculate the acceleration of the toboggan.
- **c.** Calculate the braking force on the toboggan.

4. A person riding a sled is able to provide a braking force of 225 N to bring the sled to a stop in just 2.5 s on level ground. The mass of the rider and the sled is 55 kg.

- **a.** If the sled was travelling south prior to applying the brakes, determine the acceleration of the sled.
- **b.** Calculate the speed of the sled prior to the brakes being applied.